

## ENERGY STORAGE WITH REFRIGERATION SYSTEMS AND METHOD

### CROSS-REFERENCE TO RELATED APPLICATION

[0001] This patent application is a continuation-in-part of United States Patent Application No. 10/434,171, filed on May 9, 2003.

### TECHNICAL FIELD

[0002] The present invention generally relates to refrigeration systems and, more particularly, to energy storage with refrigeration systems to reduce electricity consumption costs.

### BACKGROUND ART

[0003] With the constant evolution of technology, the demand for electricity has greatly increased in industrialized countries over the last decades. A major portion of households and offices of industrialized countries are now equipped with electrical appliances that did not exist a few decades ago. Computers, air-conditioning units, microwave ovens and home entertainment systems are a few of these appliances that are widely used in the industrialized countries.

[0004] In these industrialized countries, a major portion of the industries have adopted a Monday-to-Friday daytime work schedule. As a consequence, a generally corresponding part of the population has similar hours of activity and this has created peak-hour periods for energy demand. Accordingly, electricity consumption is higher during these hours of activity. In typical supply-and-demand logic following this peaked daytime demand, power companies have adopted two-way electricity tariffs, with cheaper rates at night.

[0005] Another field that generally involves greater daytime electricity consumption is refrigeration and air-conditioning of commercial establishments. In the warmer

months of a year, refrigeration systems and air-conditioning systems operate at full capacity during the daytime hours. During these hours, sunlight causes the outside temperature to peak. Accordingly, refrigerant head pressure in compression stages of such systems must be increased so as to enable heat exchange in a condensation stage between the refrigerant and outside air. Therefore, air-conditioning units and refrigeration systems operate at higher capacity during these warmer hours. For instance, referring to Fig. 1A, a graph A demonstrates the head pressure of refrigerant at the condensation stage throughout a summer day for a refrigeration cycle. As described previously, the head pressure peaks during the warmer part of the day. Electricity consumption is directly proportional to the head pressure. Referring to Fig. 1B, a graph B is similar to the graph A of Fig. 1A, but represents fall/spring days. Although the head pressure is relatively lower, the graph B also displays a peaked daytime head pressure.

[0006] Accordingly, energy-storage systems have been provided to be used with air-conditioning systems in order to store energy at night when the electricity rates are low, to then use the stored energy during the warmer hours of the day, to avoid daytime rates. For instance, in warmer countries, energy-storage systems having complete refrigeration cycles have been specifically designed to store energy at night in the form of a solid. The solid (e.g., ice) is then used to condense an air-conditioning refrigerant of an adjacent air-conditioning system.

[0007] These energy-storage systems comprise compression, condensation, expansion and evaporation stages, with the evaporation stage being used to cool a liquid (e.g., water) for solidification. Such energy-storage refrigeration systems are valuable investments in warmer countries, as air-conditioning systems are often used throughout the year. In cooler countries, energy-storage systems to be used with air-conditioning systems have longer

return-on-investment periods, as they are used only for a few warm months during the year. It would, however, be desirable to lower the equipment costs of this technology to render same a better investment in cooler countries.

#### SUMMARY OF INVENTION

[0008] Therefore, it is a feature of the present invention to provide energy storage to be used in combination with existing commercial refrigeration systems.

[0009] It is a further feature of the present invention to provide a method for storing energy with existing refrigeration systems.

[0010] It is a still further feature of the present invention to provide a combination of refrigeration system and air-conditioning system cooperating in storing energy.

[0011] According to the above feature of the present invention, and from a broad aspect thereof, the present invention provides a refrigeration system of the type having a main refrigeration circuit, wherein a first refrigerant goes through at least a compression stage having at least one compressor, wherein said first refrigerant is compressed to a high-pressure gas state to then reach a condensation stage, wherein said refrigerant in said high-pressure gas state is condensed at least partially to a high-pressure liquid state to then reach an expansion stage, wherein said first refrigerant in said high-pressure liquid state is expanded to a first low-pressure liquid state to then reach an evaporation stage, wherein said first refrigerant in said first low-pressure liquid state is evaporated at least partially to a first low-pressure gas state by absorbing heat, to then return to said compression stage, said refrigeration system comprising an energy-storage stage in parallel to the evaporation stage, the energy-storage stage having a container in which a medium is disposed such that said first refrigerant absorbs heat from said medium during a period of a day where the at least one compressor is less

in demand, said medium being used thereafter as a heat absorber in an evaporation stage of an air-conditioning cycle.

[0012] According to a further feature of the present invention, there is provided a combination of a refrigeration system and an energy-storage system therebetween, comprising a refrigeration system having a refrigeration circuit, wherein a first refrigerant goes through at least a compression stage having at least one compressor, wherein said first refrigerant is compressed to a high-pressure gas state to then reach a condensation stage, wherein said first refrigerant in said high-pressure gas state is condensed at least partially to a high-pressure liquid state to then reach an expansion stage, wherein said first refrigerant in said high-pressure liquid state is expanded to a first low-pressure liquid state to then reach an evaporation stage, wherein said first refrigerant in said first low-pressure liquid state is evaporated at least partially to a first low-pressure gas state by absorbing heat, to then return to said compression stage; and an energy-storage stage having a container retaining a medium and heat exchange means in a ventilation system, the container being disposed such that said first refrigerant absorbs heat from said medium during a period of a day where the at least one compressor is less in demand, said medium being directed to said heat-exchange means thereof to absorb heat from air in the ventilation system.

[0013] According to a still further feature of the present invention, there is provided a method for storing energy from a refrigeration system having a first refrigerant undergoing compression, condensation, expansion and evaporation stages of a refrigeration cycle, comprising the steps of: i) providing a container having a medium in a first state and heat exchange means for heat exchange with said medium; ii) directing a portion of said first refrigerant from the expansion stage to absorb heat from

said medium during a period of a day where the compression is less in demand, such that said medium in said container is in a second state wherein said medium is cooled with respect to the first state; and iii) cooling air of a ventilation system by heat exchange with said medium in said second state such that said medium generally returns to said first state.

#### BRIEF DESCRIPTION OF DRAWINGS

[0014] A preferred embodiment of the present invention will now be described with reference to the accompanying drawings in which:

[0015] FIG. 1A is a graph illustrating a refrigerant head pressure as a function of the time for a summer day for a refrigeration system, in accordance with the prior art;

[0016] FIG. 1B is a graph illustrating a refrigerant head pressure as a function of the time for a fall/spring day for a refrigeration system, in accordance with the prior art;

[0017] FIG. 2 is a block diagram illustrating a refrigeration system cooperating with an air-conditioning system for energy storage in accordance with a first embodiment of the present invention;

[0018] FIG. 3 is a schematic view of an energy-storing unit in accordance with the present invention; and

[0019] FIG. 4 is a block diagram illustrating a refrigeration system cooperating with an air-conditioning system for energy storage in accordance with a second embodiment of the present invention.

#### DESCRIPTION OF PREFERRED EMBODIMENTS

[0020] Referring to the drawings and, more particularly to Fig. 2, a refrigeration system in accordance with the present invention is generally shown at 10. The refrigeration system 10 has a typical refrigeration cycle having a compression stage 12, a condensation stage 14, an

expansion stage 16, and an evaporation stage 18. The stages 12, 14, 16 and 18 are interconnected for fluid connection therebetween, such that a refrigerant can be circulated therebetween.

[0021] More precisely, refrigerant in a low-pressure gas state is compressed in the compression stage 12. Therefore, the refrigerant reaches the condensation stage 14 in a high-pressure gas state. In the condensation stage 14, heat exchange is performed such that the high-pressure gas refrigerant releases energy by changing phases to a high-pressure liquid state and by lowering temperature. This is achieved by typically having rooftop condensers in which outside air absorbs heat from the high-pressure gas refrigerant. It is known that the change of phase absorbs or releases a substantial amount of energy (latent heat) at a constant temperature. Therefore, the compressor head pressure, i.e., the refrigerant pressure downstream of the compression stage 12, is a function of the temperature of the heat exchange fluid, e.g., outside air, to enable changes of phase.

[0022] A heat-reclaim loop 13 is shown in parallel to the condensation stage 14. The heat-reclaim loop 13 is used to recuperate heat rather than releasing the heat to the atmosphere, as is the case with condensers of the condensation stage 14. The heat reclaimed by the heat-reclaim loop 13 is typically used for heating the ventilation air in the winter months and for dehumidification of the ventilation air in the warmer months.

[0023] In the expansion stage 16, expansion valves reduce the pressure of the refrigerant. Therefore, high-pressure liquid from the condensation stage 14 goes through the expansion stage 16 to have its pressure lowered. Thereafter, the expanded refrigerant reaches the evaporation stage 18, wherein the refrigerant will absorb heat through a heat exchanger to cool air that is used to cool

refrigeration enclosures and display cases. The refrigerant changes phases from liquid to gas to absorb heat from the air that cools the refrigeration enclosures and display cases. The refrigeration system 10 is not limited to uses as heat absorber for refrigeration enclosures and display cases. For instance, the refrigeration system 10 may be used in arenas to create an ice surface.

[0024] It is pointed out that many additional components may be added to the refrigeration system 10, the latter being illustrated in Fig. 2 in a basic configuration. As an example, the refrigeration system 10 may be provided with defrost systems to remove solid build-up on the evaporators of the evaporation stage. Also, reservoirs, suction headers, and oil separators are well known in refrigeration systems.

[0025] Moreover, the refrigeration system 10 can be of various sizes. In the present invention, the refrigeration system 10 preferably has commercial capacities, e.g., a plurality of compressors in the compression stage 12 and evaporators in the evaporation stage 18. This will enable a more profitable return on investment for the energy-storage system, as will be described hereinafter.

[0026] In a first embodiment of the present invention, the refrigeration system 10 is used in combination with an air-conditioning evaporation stage 20. The evaporation stage 20 has heat exchangers positioned in ventilation ducts that absorb heat from ventilation air, as known in the art. In the present invention, refrigerant in suitable condition for the evaporation stage 20 is provided by an energy-storage unit 30, as shown in Fig. 2. Referring to Fig. 3, the energy-storage unit 30 is schematically illustrated. The energy-storage unit 30 has a reservoir 32 containing an energy-storing medium 34. The reservoir 32 is thermally insulated. A refrigeration heat exchanger 36 goes through the reservoir 32 for heat exchange between a refrigerant circulating in the heat exchanger 36 and the medium 34.

Lines 38 and 39 are in fluid connection with the reservoir 32. The line 39 will direct the medium 34 and direct same to the evaporation stage 20, whereas the line 38 will return the medium 34 to the reservoir 32 thereafter.

[0027] In the first embodiment, the refrigeration heat exchanger 36 is supplied with refrigerant from the refrigeration system 10. More precisely, the refrigerant is conveyed from the expansion stage 16. It is understood that the refrigerant being fed to the heat exchanger 36 can be supplied directly from the condensation stage 14, with an expansion valve 40 (included in the present invention as part of the expansion stage 16) being optionally provided upstream of the heat exchanger 36 to enable adequate expansion of the refrigerant as a function of the energy-storing medium 34. Considering the pressure of the medium 34, the refrigerant temperature supplied to the heat exchanger 36 must preferably be below the solidification temperature of the medium 34. The expansion, whether it be via the expansion stage 16 or the valve 40 of the expansion stage 16, is optionally used to create these conditions, and may be bypassed if not required. Refrigerant exiting the heat exchanger 36 has absorbed heat from the medium 34 in the reservoir 32, whereby refrigerant will change phases by evaporating, and the medium 34, e.g., water or any other suitable refrigerant, will be cooled and will possibly solidify upon reaching freezing point.

[0028] Therefore, the energy-storage unit 30 will store energy in the form of a cooled medium, using the refrigeration system 10. It has been shown in Figs. 1A and 1B that the head pressure of refrigerant is lower at night, and so is the electricity consumption. Accordingly, the compressors of the compression stage 12 are not used to full capacity at night. The heat exchanger 36 is to be cooled at night to store energy in the form of the cooled medium 34, when the electricity tariffs are low (e.g., 9:00 p.m. to



7:00 a.m.)). The insulated reservoir 32 lessens the energy loss due to the warming effect of the ambient air.

[0029] The air-conditioning loop, including the evaporation stage 20 and the lines 38 and 39, on the other hand, is used during the warmer hours of the day (e.g., 7:00 a.m. to 9:00 p.m.), when the demand for cooled air and the electricity tariffs are high.

[0030] In the evaporation stage 20, the medium 34 absorbs heat from ventilation air to cool the ventilation air. A pump 42 ensures the circulation of refrigerant in this closed loop. The highest electricity consumption in a refrigeration cycle is that required to operate the compressors. By storing energy at night, electricity consumption is increased at night and lowered during the day, as air-conditioning compressors will not be used, thereby substantially reducing electricity costs. Moreover, the use of the compressors of the compression stage 12 is optimized, as these compressors, which were for the most part inoperative at night due to the cooler outdoor temperature and the closing of, e.g., the supermarket (and thus no opening of refrigeration cabinets) is now optimized by the compression stage 12 being used at night to cool the medium 34.

[0031] Therefore, by providing a reservoir 32 of sufficient volume, enough medium 34 can be provided to suppress any air-conditioning system. In such a case, the above-described closed loop between the evaporation stage 20 and the energy-storage unit 30 would be sufficient to supply the full air-conditioning load. However, the energy-storage unit 30 is also contemplated as an auxiliary system to provide additional capacity to a combination of refrigeration system and air-conditioning system (not shown).

[0032] The energy-storage unit 30 can help reduce equipment costs in addition to the energy savings. As mentioned previously, if the energy-storage unit 30 has

sufficient volume, it can store enough energy for a day's load of air-conditioning, whereby an air-conditioning system having a full refrigeration cycle (e.g., the air-conditioning system 20) is not required.

[0033] The energy-storage unit 30 uses, in the first embodiment, refrigerant that has gone through the compression stage 12, whereby no additional compressor is necessary and thus equipment costs are minimized. Therefore, the energy-storage unit 30 is added to existing refrigeration systems (e.g., the refrigeration system 10). Moreover, the use of the compressors of the refrigeration system is optimized, as the typically unoccupied nights are now used for storing energy.

[0034] The medium 34 may be any given type of refrigerant having adequate properties to store energy. More specifically, the medium 34 must be able to change phase at a temperature above that of the refrigerant of the refrigeration system, whereby solid build-ups are anticipated about the heat exchanger 36. Water, for instance, changing phase at 0°C at atmospheric pressure, and having an enthalpy of about 144 Btu/lb, can be used as medium 34. It is pointed out that the evaporator stage 20 need not be part of a loop with the energy-storage unit 30. For instance, if water is the medium 34, it may be rejected after having gone through the evaporation stage 20, so as not to warm up the rest of the medium 34 in the energy-storage 34. In such a case, the reservoir 32 would simply be refilled before every night. Moreover, a reservoir (not shown) may be provided downstream of the evaporation stage 20 so as to temporarily contain the medium 34 that has absorbed heat. This reservoir would then be emptied into the reservoir 32, when air conditioning is no longer required (e.g., at the end of a day).

[0035] The heat reclaim 13 can have a loop that extends to the ventilation ducts, with a heat exchanger positioned

downstream of the evaporation heat exchanger, to dehumidify the cooled air.

[0036] Referring to Fig. 4, a second embodiment of the present invention is illustrated. More specifically, the second embodiment involves the refrigeration system 10 as described for Fig. 2 with the various stages, such as the compression stage 12, the condensation stage 14, the expansion stage 16 and the evaporation stage 18. The refrigeration system 10 operates as described previously for Fig. 2. The second embodiment illustrated in Fig. 4 has the refrigeration system 10 being used with the air-conditioning evaporation stage 20, as described previously for Fig. 2. More specifically, the evaporation stage 20 is in a loop with the energy-storage unit 30 by way of lines 38 and 39. However, the second embodiment involves a heat exchanger 50 parallel to the evaporation stage 18. The heat exchanger 50 is also connected to the energy-storage unit 30 by way of lines 51 and 52. More specifically, a refrigerant circulates in the lines 51 and 52 between the exchanger 50 and the energy-storage unit 30, in a closed loop. As opposed to the first embodiment illustrated in Fig. 2, in which the evaporation stage 18 was bypassed such that the refrigerant of the refrigeration system 10 would circulate in the heat exchanger 36 (Fig. 3) so as to cool the medium 34, the second embodiment has a heat exchange occurring between the refrigerant in the refrigeration cycle 10 and the refrigerant in the closed loop of the heat exchanger 50. Therefore, with respect to Fig. 3, it is the refrigerant that is in the closed loop of the heat exchanger 50 that passes through the heat exchanger 36 (Fig. 3) so as to cool the medium 34.

[0037] It is pointed out that the closed loop of the heat exchanger 50 is provided so as to reduce the length of piping of the refrigeration system 10. More specifically, hazardous refrigerants are used in typical refrigeration systems such as the refrigeration system 10, as these

refrigerants match the operation pressure and temperature fluctuations of refrigeration systems. However, as the closed loop of the heat exchanger 50 generally operates at the same temperature, a more environmentally friendly refrigerant, such as glycol, may be used to release energy to the refrigerant in the refrigeration system 10 and absorb energy from the medium 34. Accordingly, in the event that the energy-storage unit 30 is positioned at a nonnegligible distance from the evaporation stage 18, the closed loop of the heat exchanger 50 is well suited so as to reducing the length of the refrigeration system 10, and thus the quantity of refrigerant in the refrigeration system 10. It is pointed out that, although not shown, a pump may be provided on either one of the lines 51 and 52, so as to ensure that the second refrigerant, circulating in the closed loop of the heat exchanger 50, goes from the heat exchange 50 to the heat exchanger 36 (Fig. 3).

[0038] It is within the ambit of the present invention to cover any obvious modifications of the embodiments described herein, provided such modifications fall within the scope of the appended claims.